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Pollination ecology of *Commelina benghalensis* and *Cyanotis axillaris* (Commelinaceae)

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ABSTRACT

Commelina benghalensis and *Cyanotis axillaris* are perennial herbs and propagate by asexual and sexual modes of reproduction. *C. benghalensis* is andromonoecious and produces cleistogamous and chasmogamous flowers with the latter pollinated by honey bees and lycaenid butterflies. Cleistogamous flowers produce exclusively selfed-progeny while chasmogamous flowers produce selfed and cross-pollinated progeny. *C. axillaris* is a hermaphroditic with specialized androecium characterized by fertile anthers and staminal filaments bearded with dense long blue moniliform hairs, which plays multiple functions to economize the pollen for increasing pollination rate. It is pollinated by honey bees and stingless bees. The dual modes of reproduction in these two species ensure them to grow as invasive weeds.

Keywords: *Commelina benghalensis, Cyanotis axillaris,* cleistogamy, chasmogamy, deceit pollination, bees, lycaenid butterflies and elaborated androecium.

1. INTRODUCTION

The family Commelinaceae has 41 genera with 731 known species distributed mostly in tropical and sub-tropical regions (Thomas et al. 2009; Christenhusz and Byng 2016). It is characterized by succulent stems, sheathing leaves, hermaphroditic flowers with stamen arrangement in two whorls of three and capsulate fruit (Thomas et al. 2009). The genus *Commelina* with 170 species is cosmopolitan in distribution (Jyoti and Shreshta 2009). The flowers possess very delicate, short-lived and complex flowers and pollinated by deceit by generalist pollinators involving flies and bees (Faden 1992). Wei et al. (2018) reported that *C. communis* has andromonoecious sexual system adapted for facultative autogamy. It is pollinated by bees and flies, both of which collect only pollen as there is no nectar production in the flowers. Hrycan and Davis (2005) reported that *C. coelestis* and *C. dianthifolia* are typical of pollen flowers that involve feeding and fertile anthers. Vogel (1978) stated that *C. coelestis* and *C. dianthifolia* have staminodes that act as feeding anthers and mimic the presence of large quantities of pollen by deceit while fertile anthers act as pollinating anthers. Kaul and Koul (2012) reported that *C. benghalensis* and *C. caroliniana* flowers are odorless and nectar-less with sterile and fertile anthers; the sterile anthers act as an attractant while fertile anthers for pollination by visiting insects. The available information

on pollination aspects of *C. benghalensis* is insufficient to understand its reproductive biology.

The genus *Cyanotis* is paleotropical in distribution and comprises of about 56 species worldwide (Govaerts and Faden 2012) but it is very diverse in Asia and Africa (Faden 2000). Karthikeyan et al. (1989) reported 16 species of *Cyanotis* from India. But, Nandikar and Gurav (2014) documented only 13 *Cyanotis* species from India in the revision of this genus. They include *C. adscendens, C. arachnoidea, C. arcotensis, C. axillaris, C. burmanniana, C. fasciculata, C. glabrescens, C. cristata, C. pilosa, C. tuberosa, C. villosa, C. racemosa* and *C. vaga*. The traits such as compact cincinni, basally fused petals, six fertile moniliform bearded stamens, filaments and style with swollen apex characterize this genus. *C. axillaris* is a common herb in wet places in India, Sri Lanka to northern Australia and West Indies. These authors also distinguished two varieties, *axillaris* and *cucullata* in this species based on leaf and capsule characteristics but it is very difficult to identify them based on only these two characters. Pollination information on *Cyanotis* genus is almost totally lacking except some floral structural aspects. With this backdrop, the present study is contemplated to provide certain aspects of pollination ecology of the commonly occurring weeds, *Commelina benghalensis* L. and *Cyanotis axillaris* (L.) D. Don ex Sweet, both belonging to Commelinaceae.

2. MATERIALS AND METHODS

Commelina benghalensis and Cyanotis axillaris growing in wild pockets in Adavivarm area of western Visakhapatnam city was selected for study during July 2020 to July 2021. These two species were studied for their vegetative growth, flowering period, floral structural and functional aspects, sexual system, flower-visitors and their role in pollination, and fruiting ecology. All these aspects were examined in great detail to understand their sexual reproduction and also asexual reproduction with reference to their invasiveness in different habitats, especially wet areas.

3. RESULTS AND DISCUSSION

Commelina benghalensis

It is a native of tropical and subtropical Asia and Africa (Kaul et al. 2002; Santhosh et al. 2013). It is a perennial herb and forms dense mats in wet locations where it shows flowering almost throughout the year and also in dry sandy locations where it flowers during wet season only. The stem is fleshy with creeping habit which enables it root at the nodes. The plant produces aerial, sub-aerial and underground branches of which, the first two types produce leaves in spiral mode while the last one does not produce leaves. This field observation is in agreement with Kaul et al. (2002) who also reported similarly. In the present study, it is found that the aerial branches bear chasmogamous male and bisexual, and cleistogamous bisexual flowers, the sub-aerial ones only chasmogamous bisexual flowers, and the underground ones only cleistogamous bisexual flowers. The production of cleistogamous and chasmogamous bisexual flowers and chasmogamous male flowers on the same plant is an indication of the function of andromonoecious sexual system. Such a sexual system has been reported in *C. communis* by Wei et al. (2018). The chasmogamous male and bisexual flowers on aerial branches and chasmogamous bisexual flowers on sub-aerial ones are open during forenoon period only. Both chasmogamous and cleistogamous flowers irrespective of their sex are small, blue and zygomorphic. The corolla has two broad and clawed blue upper petals and one lower less prominent light blue lower petal. In both male and bisexual flowers, the stamens are six of which three upper ones are yellow, sterile and cross-shaped while the median longer yellow stamen with yellow pollen and two lateral shorter blue stamens with white pollen are fertile and dithecous indicating the existence of anther dimorphism. But, anther dimorphism, in principle, represents feeding anthers and pollinating anthers, the former refer to fodder stamens providing pollen for pollinators while the latter refer to fertile pollen intended for pollination (Faden 1985, 1992). But in *C. benghalensis*, anther dimorphism represents staminodes or dummy anthers and pollinating anthers, the former is intended to mimic large quantities of pollen to attract pollinators while the latter with fertile pollen is intended for pollination (Vogel 1978; Faden 1992). The pollinator insects while harvesting pollen as a food source from the staminodes had contact with the fertile pollen from the lateral stamens during which pollen is vectored to the stigma effecting pollination. The median yellow stamen with fertile pollen appears to serve as forage for the bees as well as for pollination for the plant. Wei et al. (2018) reported that *C. communis* flowers with no nectar production is pollinated by bees such as *Halictus, Lasioglossum* and *Amegilla,* and also by syrphid flies. In this study, *C. benghalensis* with nectariferous chasmogamous flowers is primarily foraged for pollen and nectar, and pollinated by honey bees, *Apis dorsata, A. cerana* (Figure 1a) and *A. florea* with the last two as regular foragers. Further, it is also visited occasionally by small butterflies belonging to Lycaenids of which *Zizina otis* (Figure 1b) is the frequent visitor for nectar collection. Vogel (1978) and Faden (1992) reported that anther dimorphism characterized by the division of labour between modified stamens as staminodes for pollinator attraction and those producing fertile pollen for pollination is common in Commelinaceae. Hrycan and Davis (2005) reported that in *C. coelestis and C. dianthifolia*, the flowers display anther dimorphism represented by fodder anthers for

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pollinators by deceit and fertile anthers intended for pollination. The ovary is a non-functional pistillode in male flowers and it is tri-carpellary with 5 dimorphic functional ovules (Kaul et al. 2002). In chasmogamous bisexual flowers, the style elongates after anthesis and subsequently coils contacting the fertile anthers with its stigma, which results in autonomous autogamy. Similarly, Webster et al. (2005) reported that chasmogamous bisexual flowers of aerial branches are self-pollinating and produce one large seed. These authors also noted that cleistogamous flowers of sub-aerial branches also self-pollinate by autogamy and produce one large and two small seeds. In *C. benghalensis*, seeds produced by chasmogamous bisexual flowers and cleistogamous flowers have been categorized into four types, large and small seeds from aerial and sub-aerial branches and large and small seeds from underground branches (Prostko et al. 2005; Webster et al. 2005). Cleisotogamous flowers irrespective of their position on the plant produce only selfed-progeny (Kaul and Koul 2009). In case of chasmogamous flowers, there is a display of situations of overlap in male and female phases due to protogyny and the production of sterile stamens. This is an indication of the function of a mixed mating system. Hrycan and Davis (2005) reported that *C. coelestis and C. dianthifolia* are self-compatible and facultative autogamous. Wei et al. (2018) reported that C. communis is facultative autogamous with predominant selfing. Further, Kaul and Koul (2009) reported that the production of chasmogamous male flowers is an outcome of non-functional ovary and this situation is further emphasized by the presence of a pistillode in many male flowers. Cleistogamous flowers produced on aerial branches is attributed to anthesis failure and at the same to ensure the occurrence of autogamy for fruit or seed set (Kaul et al. 2002; Koul and Kaul 2009). Fruits are enclosed by a spathe and mature within a period of two months. Fruit is a 3-celled capsule with smooth brown to black ridged seeds; it is dehiscent and splits open by 3 valves. *C. benghalensis* also propagates by vegetative mode due to creeping habit and rooting ability at each node. The study suggests that in *C. benghalensis*, the dichromatic floral color, anther dimorphism and mixed mating system appear to have evolved to maximize seed set rates in chasmogamous bisexual flowers and the genetic variation achieved through vector-mediated pollination ensures the colonization of new ecological niches. Additionally, vegetative propagation facilitates the rapid formation of populations in order to be an invasive weed in different habitats. Therefore, *C. benghalensis* with the ability to set seed through sexual and asexual mode is able to spread and extend its distribution range in tropical regions.

Cyanotis axillaris

It is a stalkless creeping succulent perennial herb with erect tops and linear to lanceolate leaves. It roots at lower nodes which touch the soil. It is common in aquatic and wet habitats, especially in cultivated fields where it blooms and fruits year-long. The flowers are born in leaf axils; they are violet blue and couched in inflated sheaths. They are open during morning hours and last for a day. The calyx is connate with 3 free sepals. The corolla is tubular with 3 broadly ovate lobes apically. The stamens are 6 on inflated filaments bearded with dense long blue hairs and the anthers are versatile in fixation. Ovary is 3-celled and each cell with 2 ovules arranged on axile placentation. The style is pilose with a capitate stigma. The flowers with no nectar production offer only pollen as reward for foraging insects. The anthers dehisce by basal pores at anthesis and all anthers produce fertile yellow pollen. The honey bees, *Apis cerana, A. florea* (Figure 1c,d) and the stingless bee, *Trigona iridipennis* visited the flowers throughout the day for pollen collection from individual anthers which are spatially separated. Fruit is a capsule with beaked apex consisting of 4-6 oblong, pitted dark brown shining seeds arranged one above the other in each cell.

Figure 1. ***Commelina benghalensis***: a. *Apis cerana* collecting pollen, b. Lycaenid butterfly *Zizina otis* collecting nectar; ***Cyanotis axillaris***: c. & d. *Apis florea* collecting pollen.

Faden (1992) reported that the flowers present hairs on any floral part and their presence is purported to have different roles such as defense against insect feeding, protection from desiccation and in the occurrence of pollination. This author also noted that the hairs pertaining to pollination occur usually on the staminal filaments. In some *Cyanotis* species, the flowers possess style and

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staminal filaments bearded with similar coloured moniliform hairs. In the present study, *C. axillaris* flowers possess hair-free style and bearded staminal filaments with violet blue moniliform hairs which are not readily distinguishable from the same colored corolla. The long dense staminal filament hairs extended beyond the corolla serve as attractant for the flower-visitor. The hairs would also provide extended surface area and footholds in order to enable the flower visitors to land and feed on the pollen. These hairs appear to have the function of retaining pollen that falls off or is displaced from the anthers so that it is accessible to the visiting insect for its collection during which the ventral side of the insect contacts the pollen for subsequent transfer. The foraging visits invariably contact the stigma, mostly with their ventral side due to which pollination occurs if the visitor body has pollen on its body. These various functions of androecial hairs ensure the reduction in pollen collection rate to make available more pollen for increasing pollination rate. In line with this, the honey bees and stingless bees recorded on *C. axillaris* in the present study have been found to spend more time on each flower to collect pollen from individual stamens as they are spatially separated from each other and from androecial hairs. Further, the bees in quest of more pollen visit the flowers in the neighborhood and in the area beyond the location. In consequence, their visits contribute not only to selfing within and between flowers of the same and different plants. Therefore, *C. axillaris* with a well-developed functional androecial structure is highly successful to economize pollen while offering it as a reward to flower visitors and achieve high pollination rate in order to maximize fruit and seed set rate, which ensures the invasion of different wet areas by its quick propagation not only by sexual mode and also by asexual mode.

4. CONCLUSIONS

Commelina benghalensis produces cleistogamous and chasmogamous flowers, the former type on the underground and aerial branches while the latter type on aerial and sub-aerial branches. Chasmogamous flowers include male and bisexual flowers. The production of both flower types and sexes by individual plants characterizes the function of andromonoecious sexual system. The flowers display anther dimorphism by the production of staminodes and fertile anthers, the former type without pollen production mimics the presence of pollen while the latter type acts as pollinating anthers. The flowers attract honey bees and lycaenid butterflies and are pollinated by deceit. Cleistogamous flowers produce only selfed-progeny while chasmogamous flowers produce both selfed- and crossed-progeny. Chasmogamous male flowers act as only pollen donors while chasmogamous bisexual flowers participate in fruit and seed production. The plant with andromonoecious sexual system, mixed mating system and vegetative mode is able to spread as an invasive weed.

Cyanotis axillaris is a hermaphroditic species. The flowers are violet blue with specialized androecium characterized by fertile anthers and staminal filaments bearded with dense long blue moniliform hairs, which plays multiple functions such as providing extended surface area and footholds for flower visitors to land and feed on the pollen, retaining pollen displaced from the anthers for utilization by the flower visitors and reduction in pollen collection rate to economize the pollen for increasing pollination rate. Honey bees and stingless bees collect pollen and pollinate the flowers. The plant with sexual and asexual modes of reproduction is able to grow as a successful invasive weed.

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Authors contributions:

All authors contributed equally.

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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